Analysis of Fog Removal Technique

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Abstract—In simple terms, fog is an atmospheric phenomenon which creates a sense of confusion and complexity to vision. In presence of fog, perception drops down to less than 1000 m. This happens due to plenty of reasons such as bad weather, haze, mist, smoke etc. In economic terms as well, it is not a positive phenomenon— transportation system is affected severely, so is aviation, navigation, surveillance. Hence it becomes imperative to devise fog reduction techniques. Over the years, researchers have come up with various techniques to reduce fog. Effectively, the composition of fog consists of air-light and direct attenuation. Air-light is because of scattering of light due to water droplets in the air which happen to make the scene appear whiter than normal, and attenuation is gradual decay in intensity of flux through a medium. This paper focuses on literature survey of techniques such as Dark Channel Prior (DCP), Improved Dark Channel Prior (IDCP), Anisotropic Diffusion, DCP with histogram specification, Improved DCP Using Guided Filter. The techniques discussed in this paper lay the foundation of results based on the following parameters: Normalized Colour Difference (NCD), Contrast Gain (C Gain), Number of Saturated Pixel, Colour Naturalness Index (CNI), Time Complexity (TC), Perceptual Quality (PQ). The software used for evaluation of efficacy is MATLAB-2015. It is observed that the best perceptual quality is obtained for IDCP with Guided Filter followed by IDCP, DCP with Histogram Specification, Anisotropic Diffusion and DCP.

Keywords- *Anisotropic Diffusion, Histogram, Attenuation, Pixel*

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I. INTRODUCTION

Fog [1-2, 20-21, 23] tends to get formed when water is suspended in the air just like cloud but at ground level. With increase in pollution, the thickness of fog increases because the particles in air allow more water droplets to get condensed.

There are different kinds of fogs occurring in nature. The categories are made based on the process that causes water droplets to form in the air. For example; radiation fog, freezing fog, valley fog, evaporation fog, advection fog. Radiation fog happens to be a seasonal phenomenon, mostly in winter. It disappears when the sun rises. It is caused by cooling of land overnight and the thermal radiation then cooling the air close to the surface. Condensation of water content occurs when air is no longer able to hold its moisture. Freezing fog occurs when water droplets remain in liquid state even in spite of temperature falling below freezing point. The condition of valley fog may go on for days. The concept behind valley fog is that when dense, cold air settles at the bottom of a valley and hotter air passes above the valley. Evaporation fog is a local phenomenon which leads to formation of frost. It happens when cold air passes over warm water and moist land. This results in formation of mist. This is a common sight around hot tubs. Advection fog is habitually seen around coastal areas. This occurs when air with high moisture content passes over a cool surface.

Certainly, condition of fog is a serious weather condition. Fog has a lot of direct consequences on people’s everyday life-health, aviation, road transport, surveillance, tracking, loss in basic visibility etc. The main reason for loss in basic visibility is scattering of light in the air due to presence of condensed water droplets.

Fog is made up of two major constituents: air-light [1, 6] and direct attenuation [1, 6]. Air-light is an effect caused because of scattering of light. Air-light makes the scene appear whiter which results in reduction in image quality [3]. Mathematically, the equation of air-light is given below (see equation 1)

$$\text{Air-light} = A\,(1-e^{-\beta d(x)}) \qquad \ldots (1)$$

Where,
A is global atmospheric light
β is scattering coefficient of atmosphere
d(x) is scene depth of xth pixel

Attenuation, in very simple language is a general term that refers to gradual reduction in strength of a signal through a medium. It sometimes called ‘loss’. Direct attenuation illustrates scene radiance and its decay in the medium. Mathematical expression of direct attenuation with respect to fog is [1-2, 5-6],

Direct Attenuation = J(x). T(x) … (2)
Where, J(x) is scene radiance
T(x) is medium transmission

When the atmosphere is homogeneous, medium transmission T(x) can be expressed as

$$T(x) = e^{-\beta d(x)} \ \ldots (3)$$

This means scene radiance is attenuated exponentially with depth.

Fog = Air-light + Direct Attenuation … (4)

Or in mathematic form, fog can be rewritten as:

Fog = J(x). T(x) + A (1-t(x)) … (5)

Organization of remaining paper is as follows; section two throws light on literature survey of five fog removal techniques[7-14, 21-22] namely: Dark Channel Prior (DCP) method [7-8], Improved Dark Channel Prior (IDCP)[11], IDCP with histogram specification[14], Anisotropic Diffusion[15], IDCP with guided filter[12-13]. Section three summarizes simulation setup parameters which contains setup parameters and performance metrics used. The fourth section compares results of all techniques. Finally, fifth section concludes the survey by comparing and summarizing all the results obtained.

II. LITERATURE REVIEW

Present section focuses on all five fog removal techniques previously mentioned. These techniques use a single image at a time.

A. Dark Channel Prior (DCP)

This technique was presented by He K., Sun, J., Tang, X in 2009. It eliminates fog by gauging air-light and transmission map. Dark channel is created by using least intensity pixels chosen from an image. For any image, Dark Channel can be computed using equation 6;

$$J_{dark}(x) = min_{c\in}\{r, g, b\}\left(min_{y\epsilon p(x)}(J_c(y))\right) \quad \ldots (6)$$

Where,
Jc is the colour channel of J
p(x) is local patch centered at x

While estimating transmission map [6], haze image equation is first normalized by A using equation 7;

$$\frac{I^c(x)}{A^c} = \frac{t(x)J^c(x)}{A^c} + (1 - t(x)) \quad \ldots (7)$$

Where,
$I^c(x)$ is the intensity of x^{th} pixel in the foggy image I
t(x) is transmission map
$J^c(x)$ is scene radiance of haze-free image
A is global atmospheric light which is a positive quantity
Dark channel of an image is nearly zero.
Hence, equation 8 holds valid;

$$J^{dark}(x) = min_{c\in\{r,g,b\}}\left(min_{y\epsilon p(x)}(J^c(y))\right) = 0 \ldots (8)$$

Since we know that t(x) is a constant while considering a patch, we can therefore rewrite equation 7 for estimation of transmission map as a new equation (equation 9);

$$\acute{t}(x) = 1 - min_{y\epsilon p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \quad \ldots (9)$$

To keep the image natural, some amount of haze is even added to the image. This is done by adding another factor, w (0 < w ≤ 1). Therefore, new estimated transmission map is given by equation 10 as;

$$\check{t}(x) = 1 - w * min_{y\epsilon p(x)}\left(min_c\left(\frac{I^c(x)}{A^c}\right)\right) \ldots (10)$$

To refine transmission map, soft matting [9] techniques and bilateral filters [10] are maneuvered.

Equation 5 of fog and image matting equation (equation 11) are comparable in nature;

$$I(x) = F\alpha + B(1 - \alpha) \ldots (11)$$

Where,
F is foreground colour
B is background colour
α is foreground opacity

Now, cost function E(y) has to be minimized by rewriting t(x) and$\tilde{t}$(x) as t and$\tilde{t}$ respectively. (Refer to equation 12)

$$E(y) = t^T Lt + \lambda(t - \tilde{t})^T(t - \tilde{t}) \ldots (12)$$

In this function, first expression denotes smoothness and second expression denotes data term with weight λ. A Laplacian matrix [6], L is defined whose elements are defined by equation 13;

$$\Sigma_{k|(i,j)\epsilon w_k}\left(\delta_{ij} - \frac{1}{|w_k|}\left(1 + (I_i - \mu_k)^T\left(\Sigma_k + \frac{\varepsilon}{|w_k|}U_3\right)^{-1}(I_j - \mu_k)\right)\right) \ldots (13)$$

Where,
I_i and I_j are colours of input image I at pixel i and j
δ_{ij} is Kronecker delta
μ_k and Σ_k are the mean and covariance matrix of colours in window w_k
U_3 is a 3×3 identity matrix
Ɛ is regularizing parameter
$|w_k|$ is the number of pixels in the window w_k

Bilateral filer is there to preserve the edges of an image. To estimate air-light, we pick the top 0.1% brightest pixel of dark channel prior and then the pixel having highest intensity in the image I is considered as air-light. Finally, restoration takes place in which image is recuperated using equation 14;

$$J(x) = \frac{(I(x) - A)}{(max(t(x), t_o))} + A \ldots (14)$$

Where,
t_0 is lower transmission limit.
Block diagram of DCP is displayed in Fig 1:

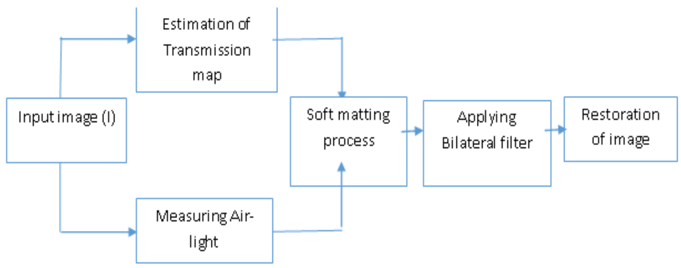

Fig. 1: Block diagram of DCP

The advantage of this technique is that only a single image of the scene is required to restore the image, and transmission map is computed accurately.

However, there are disadvantages too like; multiple assumptions have been made to estimate air-light, this technique may hold invalid if scene object looks similar to air-light (i.e. maybe the object in the scene is white in colour), this technique produces halo effect in areas of discontinuous depth, use of soft-matting technique adds to the time complexity of the entire technique.

B. Improved Dark Channel Prior (IDCP):

This technique was presented by Yan Wang and Bo Wu in 2010. The underlying principle of this technique is similar to DCP yet IDCP provides better results for estimation of air-light by the means of increasing the patch size from 15 × 15 in DCP to 31 × 31 in IDCP. IDCP does not use soft matting, hence the time complexity of this technique reduces significantly.

The block diagram of IDCP is shown in Fig. 2 below:

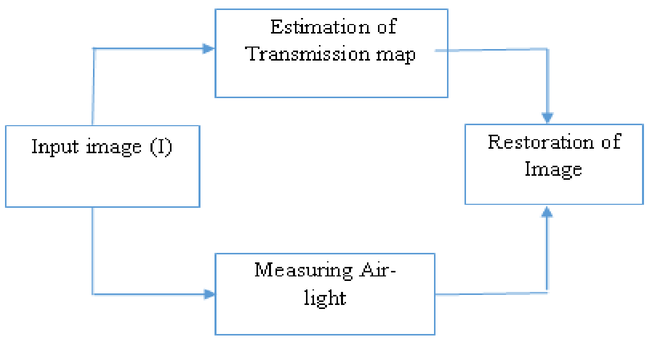

Fig. 2: Block diagram of IDCP

In this technique as well, dark channel is calculated using equation 6. After that, to estimate transmission map the same

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steps are followed from equation 7 to 10. In IDCP, atmospheric light is accurately estimated among pixels with thick haze since the size of the window has been increased from 15 to 31. Thereafter, air-light is calculated by following steps:

1. Locate a region which is apparently farthest from the camera and use of a rectangle to mark the region.
2. To measure atmospheric light, calculate dark channel of the marked rectangular region.

Finally, the image is restored by using equation 14. In IDCP, lower limit of transmission map is incremented from 0.1 to 0.35 to make the sky look smoother as well as brighter.

This technique has an edge due to the following reasons; the atmospheric light is perfectly calculated by incrementing the size of the window from 15 to 31, also time complexity is significantly reduced because this technique doesn't employ the use of soft matting, significant sky turns brighter and smoother.

The disadvantage of IDCP method continues to persist from DCP; it produces halo effect in the area of non-uniform depth, estimation of transmission map is not done properly.

C. Aniostropic Diffusion

This technique was brought forward by A.K. Tripathi and S. Mukopadhyay in the year 2012 in order to enhance contrast of an image using HSI plane. In this technique, anisotropic diffusion is used to refine air-light map acquired via DCP method. Here, post processing is done via histogram stretching which helps in improving contrast of an image.

Block diagram of Anisotropic Diffusion is in Fig 3 below:

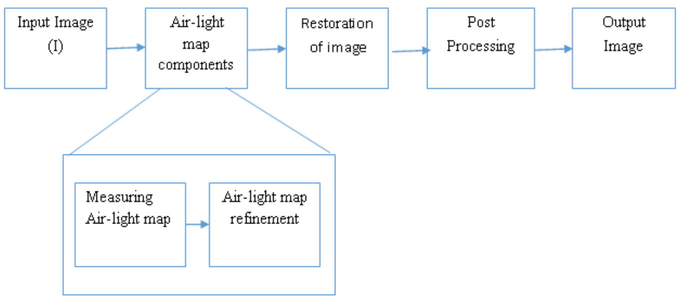

Fig. 3: Block diagram of Anisotropic Diffusion

Air-light is a positive quantity which is roughly calculated by equations given below:

$$A(x,y) = \underset{c\varepsilon(r,g,b)}{min} (I^c(x,y)) - \underset{c\varepsilon(r,g,b)}{min} \left[I_0^c(x,y) \left(1 - \frac{A(x,y)}{I_\infty} \right) \right] \quad \ldots (15)$$

$$min_{c\varepsilon(r,g,b)}(I_0^c(x,y)) \simeq 0 \cdots (16)$$

$$min_{c\varepsilon(r,g,b)}(I^c(x,y)) \geq A(x,y) > 0 \cdots (17)$$

$$A_{0(x,y)} = \beta\ {}_{c\varepsilon(r,g,b)}min\ (I^c(x,y)) \cdots (18)$$

$$A_{0(x,y)} = \beta\ {}_{c\varepsilon(r,g,b)}min\ (I^c(x,y)) \cdots (19)$$

Where, β is constant whose value is between 0 and 1. Refinement of air-light can be estimated using the following equation (20);

$$A^{t+1} = A^t + \lambda[\alpha\nabla A^t] \ldots (20)$$

where,
α is conduction coefficient
∇ is gradient operator
λ is smoothening parameter whose value lies between 0 and 1.
The discrete version of equation 20 is given by Perona-Malik, see equation 21;

$$A(x,y,t+1) = A(x,y,t) + \lambda[\alpha_N(x,y,t)\nabla_N A(x,y,t) + \alpha_S(x,y,t)\nabla_S A(x,y,t)] + \alpha_E(x,y,t)\nabla_E A(x,y,t) + (x,y,t)\nabla_W A(x,y,t) \quad \ldots (21)$$

Where
N, S, E, W represents North, South, East, and West respectively.
∇ indicates nearest neighbour differences.
The image is restored using equation 22;

$$I_0(x,y,c) = \frac{(I(x,y,c) - A(x,y))}{(1 - (A(s,y)/I_\infty(c)))} \ldots (22)$$

Advantages of this method are that air-light is estimated accurately and the contrast of image is improved due to post processing. The disadvantages, however, are that transmission map is not estimated accurately and overall natural visibility of the image is not improved.

D. DCP with Histogram Specification

This technique was put forward by Shuai Yang, Qingsong Zhu, Jianjun Wang, Di Wu, and Yaoqin Xie in the year 2013. This technique aims to overcome the defects of DCP techniques by enhancing contrast of the image when haze is removed. It aims to lighten the background region by building histogram. To attain this, this technique converts R, G, B image into HSI plane using equations given below:

$$H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B > G \end{cases} \cdots (23)$$

Where,

$$\theta = across \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}} \quad \ldots (24)$$

$$S = 1 - \frac{3}{R+G+B}[min(R,G,B)] \ldots (25)$$

$$I = \frac{1}{3}(R,G,B) \ldots (26)$$

DCP with histogram specification can be run on two kinds of images and each image uses a different algorithm. Following are the algorithms:

1) Algorithmic design for image which has gigantic background with low contrast:
   First, take the input of the foggy image I(x,y) and create a histogram P for the image. Calculate the intensity $_{xp}$ for highest intensity region. Second, compute dark channel same way done in DCP. Then calculate air light and transmission map. Refine the acquired transmission map using soft matting or bilateral filter. Finally, restore the image using the same formula as in DCP. Third, create histogram Q for the recovered fog free image. Mark sharp point $_{xq}$ on the histogram Q. About $_{xq}$, divide the histogram into two parts Q1 and Q2. Q1 is low intensity part (foreground distribution) and Q2 is high intensity part (background distribution). Fourth, recreate Q2 and by

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the use of quadratic function replace Q2 by allocating $_{xp}$ and $_{xq}$ as start point and end point respectively. Fifth, merge Q1 and recreated Q2. Implement histogram specification to rebuild the histogram Q. Sixth, restore contrast enhanced image.

2) Algorithm for general foggy image:
First, take the input of the foggy image I(x,y) and create a histogram P for the image. Calculate the intensity x_p for highest intensity region. Second, compute dark channel same way done in DCP. Then calculate air light and transmission map. Refine the acquired transmission map using soft matting or bilateral filter. Finally, restore the image using the same formula as in DCP. Third, create histogram Q for the recovered fog free image. Mark sharp point x_q on the histogram Q. About x_q, divide the histogram into two parts Q1 and Q2. Q1 is low intensity part (foreground distribution) and Q2 is high intensity part (background distribution). Fourth, recreate histogram by choosing right edge of Q1 and extending it to Q2. Fifth, implement histogram specification to rebuild Q. Sixth, restore the image.
Major advantages of DCP with histogram specification are that it brighten ups the background region, the image procured after recovery looks more natural, noise from the image is also eliminated.

Disadvantages of DCP with histogram specification are that in situation of unusually high intensity of foreground and background region, it doesn't enhance outcomes. Also, it generates grey scale degeneracy on image during histogram specification.

E. Improved Dark Channel Prior Using Guided Filter:

IDCP technique was proposed in order to do away with halo effects. IDCP using guided filter [13] was proposed by Yingi Xiong, Hua Yan, Chao Yu in 2013. IDCP employs imaging law of densest region to compute air-light in a more accurate way. Also, this technique provides an auxiliary mechanism of estimating transmission map which uses guided filter. Block diagram of IDCP based on guided filter is given below in Fig 4.

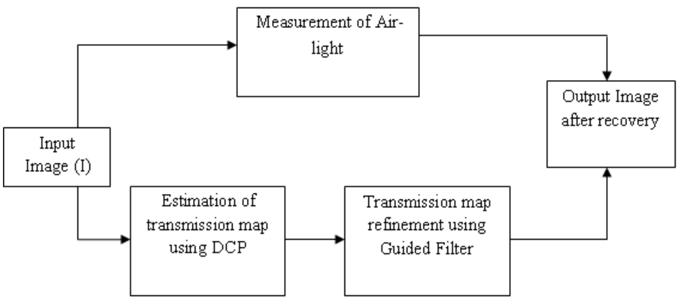

Fig. 4 Block diagram of IDCP using Guided filter

In this technique, dark channel is computed for foggy image using equation 6. To calculate air-light, choose densest region and follow the steps:

1 The pixels chosen from densest region should fulfil following two conditions-

$$f(x,y) = max_{c\in(R,G,B)} I^c(x,y) - min_{c\in(R,G,B)} I^c(x,y) < \alpha \quad \ldots (27)$$

where,
f is foggy image deviation map and α is constant ranging from 1 to 5.
The chosen pixel is in the top 0.5% brightest pixel of the dark channel calculated.

2 Choose A as maximum R, G, B value among densest region pixels. If A is zero then increase the value of α and go to (1).

Transmission map is estimated using following mechanism:

$$t'(x,y) = \begin{cases} 1, f(x,y) < \sigma \text{ and } I(dark)(x,y) > \mu \\ \bar{t}(x,y) \end{cases} \quad \ldots (28)$$

Where, $\check{t}(x,y)$ is given by equation (10) explained in DCP method. The value of σ should lie between 4 to 10 and μ is calculated by Otsu's method.
The advantages of this technique is that it eradicates the problem of halo effects, transmission map estimation is refined up to a great level, more accurate results of atmospheric light can be drawn. The disadvantage is that air-light is not computed accurately and it is unable to improve contrast of image.

III. Simulation Setup Parameters

This section discusses the setup parameters of the workstation, the input images, the efficacy software used, and performance metrics based on which all fog removal techniques are compared.

A. Setup Parameters

The CPU specification for the experiment is 4005U @ 1.70 GHz and processor used was Intel® Core™ i3 with RAM of 4GB. The simulation platform used was MATLAB 2010 version. Three different images were chosen; woods, rural morning, and pond. Each image is in four different sizes of 64 × 64, 128 × 128, 256 × 256, 512 × 512. The image type is PNG. All images used are colored images.

B. Performance Metrics

1. *Normalised Colour Difference (NCD):* This parameter is used to gauge the colour variation among the natural (de-fogged) image and foggy image. The definition of NCD says that it is the deterioration of colour quality in the image.
2. *Contrast Gain [16]:* This parameter is used to compute mean contrast distinction between de-fogged and fogged image.
3. *Number Of Saturated Pixel (σ) [17]:* It is expressed as $\sigma = \frac{n}{X \times Y}$, where n is the number of saturated pixels in the entire image after application of fog removal technique has been implemented.
4. *Colour Naturalness Index (CNI) [18-19]:* This parameter evaluates the extent of similarity between human perceived image and natural world.
5. *Time Complexity (TC):* This is defined as time taken in total by algorithm of each technique to remove fog from an image. It is expressed in seconds.

6. *Perceptual Quality :* The image recovered after applying defogging technique should have high perceptual quality so that image looks natural to the observer i.e. it shouldn't possess colour blurriness in any form and it should look as close to nature as possible.

IV. RESULTS

In this section, results computed for all performance metrics on all defogging techniques are presented based on performance metrics written in section 3B.

A. Impact On Perceptual Quality:

Fig 5 displays the snaps of output of all fog removal techniques (algorithms) upon running them on MATLAB-2010. It can be deduced from looking at the images in Fig 5 that IDCP using guided filter is the best because it completely discards the effect of halo, there is absolutely no blurriness and no odd region.

Original Image	Dark Channel Prior	Improved Dark Channel Prior	IDCP with histogram specification	Anisotropic Diffusion	IDCP using guided filter

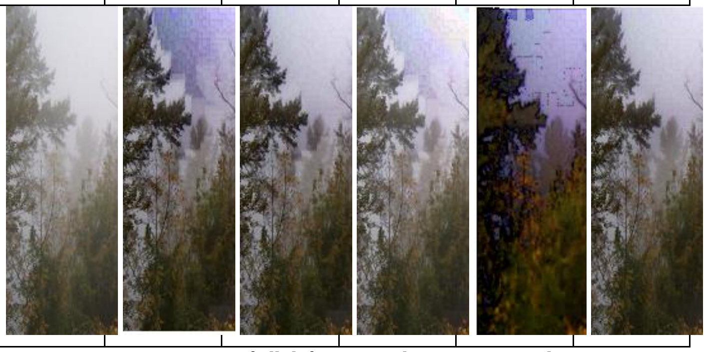

Fig 5: Snaps of all defogging techniques reviewed

B. Impact On TC, NCD, C_{GAIN}, σ, CNI:

The results of for all sizes of all image are recorded in different tables. Table 1-3 below depicts results of wood.png for all performance metrics and all sizes; 64×64, 128×128, 256×256, 512×512.

Table 1: Impact of TC, NCD, C_{gain}, σ, CNI on Wood image

Wood.png	Parameters	64×64	128×128	256×256	512×512
DCP	TC	1.524912	3.035971	8.260957	33.701064
	NC	0.1357	0.2709	0.3789	0.4712
	Cgain	0.0376	0.0556	0.0696	0.0733
	σ	0	5.09E-06	1.02E-05	4.07E-05
	CNI	0.535	0.5753	0.6528	0.7174
IDCP	TC	1.159501	2.011849	5.404304	21.759435
	NCD	0.1079	0.1733	0.2547	0.2945
	Cgain	0.0255	0.0453	0.059	0.0614
	σ	0	8.63E-08	1.01E-05	2.07E-05
	CNI	0.5112	0.5347	0.5758	0.5873
IDCP WITH HISTROGRAM SPECIFICATION	TC	1.772841	3.903256	8.291213	34.094078
	NCD	0.0882	0.1104	0.1586	0.1839
	Cgain	0.025	0.0266	0.0284	0.0259
	σ	0	1.02E-05	2.90E-05	3.07E-05
	CNI	0.5029	0.504	0.5238	0.5258
IDCP (GUIDED FILTER)	TC	1.465423	2.945942	8.00921	25.637924
	NCD	0.1002	0.1624	0.2338	0.2838
	Cgain	0.0249	0.0346	0.0479	0.0511
	σ	0	0	0	0
	CNI	0.5209	0.5536	0.5936	0.5601
ANISTROPIC DIFFUSION	TC	1.424351	2.775264	6.746964	22.811441
	NCD	0.7102	0.5556	0.5379	0.5222
	Cgain	0.2481	0.2099	0.1871	0.1456
	σ	0.0081	0.0236	0.0738	0.2548
	CNI	0.9113	0.8776	0.8665	0.8524

1. *Influence on Time Complexity:*

Table 1. shows results for impact of different fog removal techniques on time complexity for image wood.png. It can be clearly seen that time taken is least i.e. the best by IDCP algorithm. Such a result is seen because IDCP algorithm doesn't employ soft-matting technique for transmission map refinement. On the other hand, DCP with histogram specification takes the most time to remove fog from an image. This is so due to the fact that DCP uses both soft-matting technique as well as histogram specification for background contrast improvement.

2. *Influence on Normalised Colour Difference (NCD):*

Table 1. shows results for impact of different fog removal techniques on NCD for image wood.png. It can be deduced that NCD has leading result for DCP with histogram specification algorithm. Lower the NCD value, the better is the result. As size of the image increases, NCD also increases except for Anisotropic diffusion.

3. *Influence on Number of Saturated Pixel (σ):*

Table 1. shows results for impact of different fog removal techniques on σ for image wood.png., different sizes. σ has best result for IDCP Guided Filter with 0 as value. This means that not even one pixel is saturated after application of fog removal technique on the image. The result is then followed by DCP. Lower the value of σ, the better is the result. As the size of the image increases, value of σ also increases except for IDCP Guided Filter. IDCP Guided Filter's σ reminds constant irrespective of the size of the image.

4. *Influence on Colour Naturalness Index (CNI):*

Table 1. shows results for impact of different fog removal techniques on CNI for image wood.png., different sizes. It is at its prime for anisotropic diffusion with maximum value followed by DCP. Higher the value of CNI, better it is since the picture after recovery will appear more natural. As size of image increases, value of CNI also increases while CNI decreases for Anisotropic Diffusion with increase in image size.

V. CONCLUSION

This section focuses on drawing a conclusion for various fog removal techniques mentioned in Section 2 which have been gauged and compared in terms of performance metrics as described in Section 3. After analysis following conclusions have been made;

1. IDCP using Guided Filter technique happens to be the most optimum for fog removal as compared to all other techniques.
2. As far as time complexity is concerned, IDCP shows significantly good results. However, IDCP has low perceptual quality. But, IDCP with guided filter has high time complexity and high perceptual quality. Here there is a trade-off between time complexity and perceptual quality.
3. IDCP using guided filter provides best perceptual quality.
4. DCP with Histogram specification provides best NCD results.

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